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State-of-the-art in Residential and Small Commercial Air Handler Performance

I.S. Walker

Environmental Energy Technologies Division

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Introduction

Although furnaces, air conditioners and heat pumps have become significantly more efficient over the last couple of decades, residential air handlers have not experienced similar improvement. The most common air handlers have efficiencies of only 10% to 15% (Phillips 1998, Gusdorf et al. 2002). These low efficiencies indicate that there is significant room for improvement of both electric motor and aerodynamic performance of air handler fans. The need to address this poor performance has been known for many years. For example, Ariewitz et al. (1983) developed a high efficiency blower for heat pump applications to address this issue.

An important consideration in analyzing air handlers is the fact that essentially all of the wasted electricity is manifested as heat. This extra heat reduces air conditioning cooling and dehumidification performance and effectively acts as fuel switching for fossil fuelled furnaces. For electric furnaces, this heat substitutes directly for the electric resistance heating elements. For heat pumps, this heat substitutes for compressor-based high COP heating and effectively reduces the COP of the heat pump.

Using a combination of field observations and engineering judgment we can assemble a list of the factors that lead to low air handler efficiency and potential solutions, as shown in Table 1. None of the problems require exotic or complex solutions and there are no technological barriers to adopting them. Some of the solutions are simple equipment swaps (using better electric motors), others require changes to the way the components are built (tighter tolerances) and others relate to HVAC equipment design (not putting large fans in small cabinets).

Table 1. Issues for improving air handler performance

Issue	Solution
Clearances between fan blades and housing (or scroll) can result in turbulent air flows around blade edges.	Improve design of fan housing.
Aerodynamics of blades and housing.	Improve aerodynamics (readily available in other air moving applications).
Electric motor efficiency.	Use higher efficiency motors, e.g., Brushless Permanent Magnet (BPM).
Fans are fitted in restrictive furnace cabinets.	Integrate design of furnace cabinets.

Beyond California, there is a range of other interested parties. Oregon and Washington have mechanical ventilation requirements whose energy implications depend on fan performance. Utility programs that offer rebates for better fans need to understand all the implications and have better information for estimating energy and peak power reductions. Since much of the technology already exists, the Building America experts meeting in January 2004 identified air handler fan power reductions as a high priority goal that can easily be achieved in a short time frame given sufficient support from DOE.

Residential Air Handler Characteristics

PSC motors with forward inclined blade blower wheels

This is by far (>90% of the residential market) the dominant air handler used today. The permanent split capacitor (PSC) motor usually operates at three or four fixed speeds over a range of air flow rates, with highest air flows about 1.5 times the lowest air flows. Different speeds are necessary to match the different airflow requirements for heating and cooling operation. Speed is controlled by changing jumpers on the control board located on the fan housing and/or spade-lug connectors on the motor. Due to the way the speed is controlled in a PSC motor, a fan operating at a fractional speed consumes approximately the same power as one operating at full speed, with an accompanying decrease in efficiency. The relatively constant speed settings mean that the air flow is highly variable with static pressure. As shown in Figure 1, the blower wheel has many narrow chord forward curved bent sheet metal blades, with large gaps between the wheel and housing. The housing has one opening each side with the direct drive motor located in one of these openings (Figure 2), and a rectangular discharge. This side entry means that the air flow pattern inside the air handler cabinet is fairly convoluted as air typically enters the bottom of cabinet, flows around the housing then changes direction 90° to enter the blower wheel. Also, unlike older belt-drive blowers, the mounting of the electric motor in the inlet restricts the flow on that side of the fan.

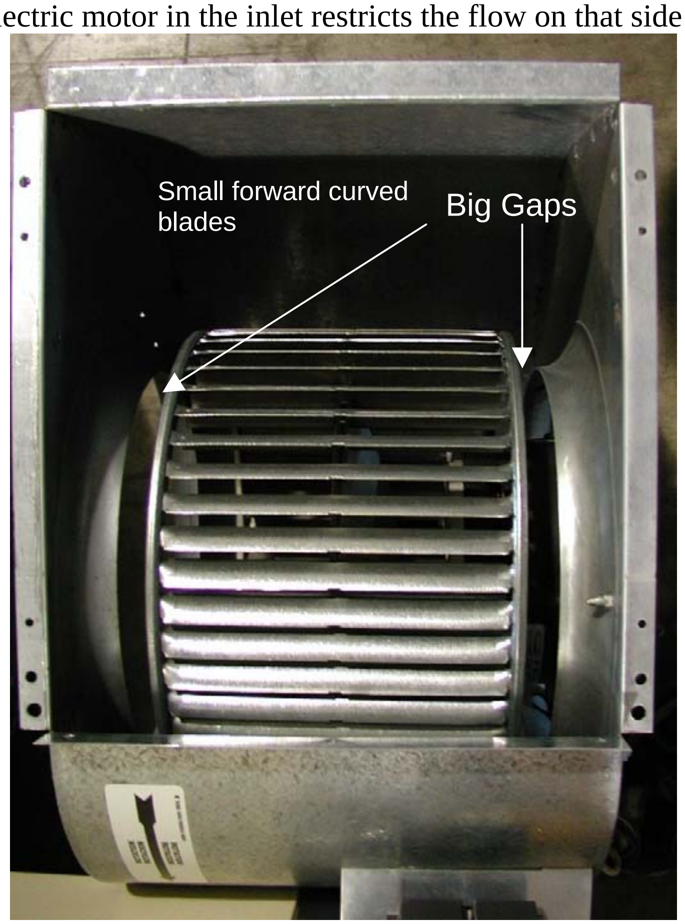

Figure 1. Typical air handler blower viewed from the air exit.

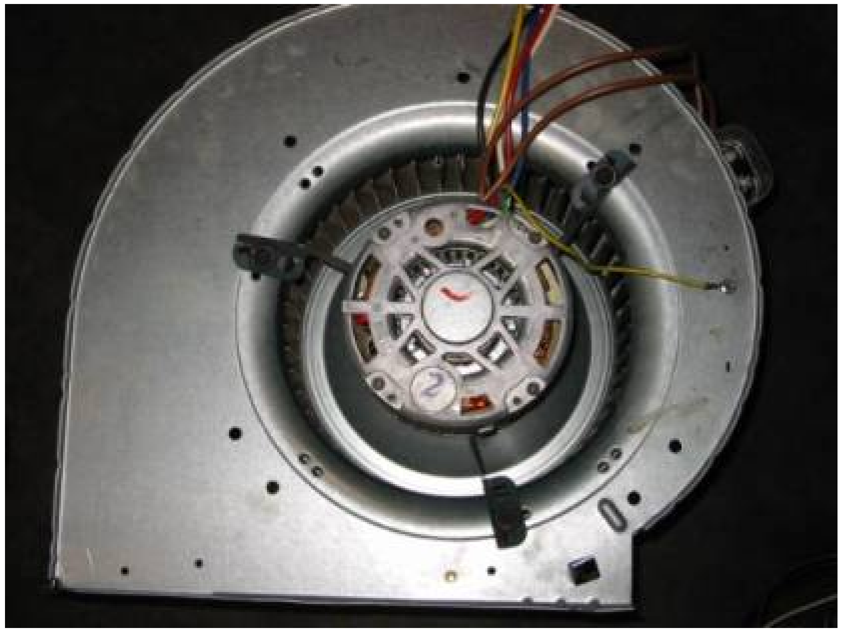

Figure 2. PSC motor mounted in inlet

BPM motors and forward inclined blade blower wheels

Brushless Permanent Magnet (BPM) DC motors are generally more efficient than the PSC motors and allow a wider range of operating speeds. For this reason they are more common in multiple speed heating and cooling applications. A key characteristic related to their wide speed range is their ability to operate at much lower air flow rates, making them more suitable for continuous fan operation for mixing and/or distribution of ventilation air. The ability to operate at much lower air flows (usually about 2.5 times less than the maximum air flow) results in considerably less power being used at low fan speeds. The blower wheel and housing are the same as those used with PSC motors. The BPMs are about the same diameter[1] (as can be seen by comparing Figure 2 to Figure 3), but are longer than the PSC motors and therefore fill more of the air inlet on one side of the fan and add to air flow resistance and nonuniformity of the air flow.

Since the speed of a BPM is electronically controlled, it can be set specifically to match the airflow requirements for each application. Furthermore, BPMs can be operated to maintain airflow regardless of the static pressure across the fan, e.g. when filters become dirty and restrict airflow. This helps maintain an airflow range through the heat exchanger, close to the optimal flow rate for which they were designed.

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[1] Both PSC and BPM motors we tested had 5.5 inch diameter housings and were mounted in 9 in. diameter blower wheels.

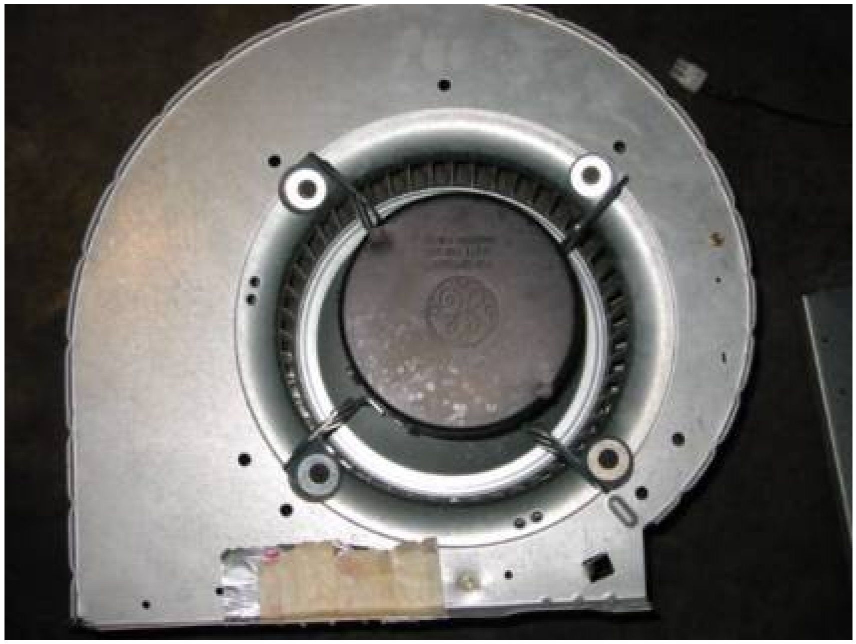

Figure 3. BPM mounted in inlet

Furnace Performance Effects

For furnaces the waste heat from the air handler acts to increase the effective capacity of the furnace. For electric furnaces the effect is simply a capacity increase. For heat pump furnaces, the effect is similar to the use of backup (or strip) heat, and the effective COP is reduced. For fossil fueled furnaces the result is fuel switching from gas/oil to electricity. The economic aspects of lowering COP for heat pumps, fuel switching and changing building load depend on local costs of different fuels, but generally displacing fossil fuels with electric resistance heat will result in higher heating costs.

For staged furnaces, the lower capacity modes can utilize lower fan speeds. Field studies (Pigg (2003), Pigg and Talerico (2004)) have shown that staged gas furnaces typically operate such that high fire mode is only used to recover from setback and that for cold climate houses with sheet metal ducts in basements the majority of operation is in low-fire mode. For houses more typical of California, with duct systems outside conditioned space (with their increased losses particularly in fan-only mode) we expect the fan-only operation to increase the building load and require more furnace operation and possibly change the high-fire to low-fire ratio. Pigg and Talerico (2004) showed that typical reductions in power consumption were from 500W to 325W at 1000 cfm when comparing PSC to BPM furnaces. For BPM motors in that application the low-fire (and hence lower air flow) mode results in significant power and energy savings compared to a PSC motor that does not reduce its power and energy requirements with air flow rate.

Air Conditioner Performance Effects

As air conditioners have become more efficient, the fraction of total energy consumption for the HVAC system attributed to the air handler fan has increased, thus making the air handler fan a greater contributor to the overall system energy use. The waste heat from the electric motor that is placed in the air stream in a modern direct drive air handler heats the air flowing through the air handler and acts to reduce the effective capacity of the air conditioner. The effect on air conditioner performance means that in addition to the energy used by the air handler itself, something like 40% (for a COP of 2.5) of the added heat appears as extra energy used to meet this extra cooling load. Older air handlers used belt drives and could place the electric motor outside the airstream and thus the waste heat did not go into the conditioned air (although if the air handler was inside the conditioned space, e.g., in a closet, then the waste heat would heat up the space and add to the space conditioning load).

Of particular interest in California is the effect of on-peak cooling system operation. A combination of field studies (Proctor and Parker (2000), Pigg (2003), Pigg and Talerico (2004) and Gusdorf (2002, 2003)) and simple steady-state analyses indicate that the air handler adds about 12% to 20% to the power consumed during air conditioner operation. The more efficient the air conditioner, the bigger the effect of the air handler fan power. Proctor and Parker gave an example that showed for a 1980 air conditioner with an EER of eight, the air handler is 12% of power consumption, but for a 2000 air conditioner with an EER of 12, the air handler is now 18% of the power.

Ventilation Systems Performance Effects

The performance of air handlers as part of a whole house ventilation system is becoming more important as more houses require the use of mechanical ventilation to maintain indoor air quality. As more jurisdictions (and possibly the State of California) turn to mechanical ventilation requirements in codes we need to be able to provide the building industry (and homeowners) with ways to meet ventilation requirements without using lots of energy.

Issues of air handler efficiency are more important for ventilation systems that utilize the air handler fan and run the air handler for extended hours beyond that needed solely for heating and cooling. Using data in Table A6.3 of ARI 210/240 (ARI 2003) the typical number of combined heating and cooling hours in the US is about 3000. This leaves 5760 hours of the year when the system could be operated in fan-only mode. Increasing operation time by roughly a factor of three leads to greater energy use and has increased the benefit of having air handler fan energy use included in ratings or standards. For heating, the air handler inefficiency leads to heating of the home. For cooling situations, this is an increase in building load. For heating situations this offsets the heat provided by the furnace with what is effectively electric resistance heating. Gusdorf et al (2003) showed electrical savings of 74% during the heating season and 48% during cooling operation for BPMs compared to PSC motors in side-by-side calibrated test houses. Similar results are reported by Pigg and Talerico (2004) in field monitoring of 31 houses.

Although the savings for BPM vs. PSC motors is greatest at lower ventilation flows, the field survey from Pigg and Talerico (2004) showed that many installations had unnecessarily high flows for fan-only operation. This needs to be addressed through better training and product information for installers.

Although not driven by air handler fans it is informative to also look at small local ventilation fans. Individual exhaust fans typically used in bathroom and kitchen vents are often worse than air handlers, but some products and operate at up to 4 cfm/W (about 10% efficiency). The Home Ventilating Institute (www.hvi.org) provides power consumption data for a few ventilation fans. Most of these ratings are for air-to-air heat recovery ventilation systems and few listings are provided for exhaust fans and kitchen fans.

Zoned Systems

Zoned systems present a particular challenge. Ideally, a zoned system should use reduced air handler flow[2] and heating/cooling capacity when serving only one zone, e.g., for houses with two equal sized zones a factor of two reduction in air handler flow would be required. BPMs would have a significant advantage in that they are able to provide the lower air flows required for this application. However, zoned installations rarely operate in a reduced capacity and air flow mode when serving only a single zone due to lack of multi-speed compressors, equipment controls or incorrect control operation. This reduces the potential for energy savings from using BPMs and also leads to other system performance problems because the high air flow through the ducts of a single zone are higher than they were designed for. This leads to excess static pressures and too much air flow (that combine to further increase energy use), increased duct leakage and noise problems.

Field and Laboratory Studies

Field studies by many researchers (see Bibliography) have shown that existing fans in residential air handlers typically consume about 500W, supply about 2 cfm/W and have efficiencies on the order of 10% to 15%. In particular, California homes showed a higher than average consumption of about 570W (Proctor and Parker 2000 and Wilcox 2004) equivalent to 510W/1000 cfm or about 2 cfm/W. The results of the California Energy Commission field survey currently nearing completion that focuses on new construction in California show similar results, with an average of about 700W per system and 2 cfm/W.

A CMHC (1993) study showed that typical furnace fan efficiencies are on the order of 15%, but poor cabinet and duct design can reduce this to about 7%. The spread from best to worst systems was on the order of ten to one indicating that it is possible to have much better performance using existing technologies. Another Canadian study by

[2] Some zoned systems use air bypass to maintain flow across the coil but allow reduced flow through the duct system to the single zone. However, this technique leads to low coil air temperatures that increase the risk of frost formation and coil freeze-up (or leads to extra compressor cycling if a potential coil freeze-up sensor is used), reduced coil heat transfer efficiency, increased duct losses, and cold air delivery – all of which should be avoided.

Phillips (1998) performed field tests on 71 houses and found air handler efficiencies in the range of 10-15%.

More recently, the Energy Center of Wisconsin (Pigg (2003) and Pigg and Talerico (2004)) tested 31 houses with new (less than three years old) furnaces during the heating season. Fourteen furnaces were variable speed with BPM, 16 were single stage with PSC motors and one was a two-stage non-BPM furnace. A combination of short term diagnostics and long term monitoring over a heating season were used to evaluate the performance of the air handlers.

Almost all the BPM furnaces used more electricity in these real installations than their DOE test procedure ratings suggest: with a median increase of 82%. This was attributed to the static pressures in these field installations being much higher than those used in rating procedures. Test procedure external static pressures were 0.20 or 0.23 inches of water (50 or 75 Pa) depending on the furnace capacity. The measured field data showed a range of 0.24 to 1.9 inches of water (60 to 249 Pa) with an average of 0.5 inches of water (125 Pa) at the high fire rate.

The BPM air handlers substantially reduced electricity consumption during furnace operation. The average BPM equipped furnace used about 0.5 kWh of electricity per therm of gas consumed, which is about half what was measured for the non-BPM furnaces. That translated into about 400 kWh less electricity over the course of an average heating season in Wisconsin. This level of energy use corresponds to about 5% of the electricity used in the houses.

In standby mode, the BPM furnaces used about 4 W more than PSC furnaces, with the range of standby power being 4 W to 13W. It is important to track differences such as these when comparing year-round electricity use between different air handlers and different operating modes (continuous operation vs. non-continuous operation).

Natural Resources Canada (Gusdorf et al. (2003 and 2004)) have tested two side-by-side calibrated test houses to evaluate the change in energy for using a BPM rather than a PSC motor for continuous fan operation as required in many Canadian houses. Laboratory tests of the air handlers used in the study showed PSC efficiencies in the range of 10 to 15% with BPM efficiencies of 17 to 18% over the range of flows used for heating and cooling. The biggest differences were for continuous operation where the BPM was six times more efficient than the PSC by being able to operate at about half the flow rate of the PSC during continuous operation. The results of this study showed that for the heating season there was a 74% reduction in electricity use for using a BPM (26% of the whole-house electricity use). There is a corresponding increase in natural gas usage in the heating season of 14% to account for the reduction in waste heat from the electric motor. For cooling the savings were 48% of fan energy and 21% of all air conditioner use.

Prompted by a combination of DOE's desire to evaluate a new prototype air handler, PG&E's desire to evaluate its BPM rebate program and the CEC's desire to have technical input for potential T20 and T24 changes, LBNL and PG&E have been performing laboratory testing of air handlers for the past couple of years, and continue this work in the current project. PG&E prepared a CASE report on Residential Air Handler (PG&E (2003)) that provides a good overview of many of the issues discussed here.

The preliminary laboratory studies by LBNL's Energy Performance of Buildings Group (Walker et al. 2004) performed tests on a single furnace using two air handlers: a standard PSC and a new BPM prototype with an improved impeller wheel and fan housing. The two air handlers were evaluated using a laboratory duct system that has been designed to be typical of California construction practice. In addition, LBNL obtained a second prototype and used an outside contractor to perform standardized testing (Biermayer et al. 2003).

The current study combines measurements made by PG&E using a standard AMCA 210 (Laboratory Method of Testing Fans for Aerodynamic Rating Performance) type air handler test and additional LBNL laboratory tests. The current study includes a further pair of furnaces that have three air handlers: standard PSC, current BPM and a second prototype with an advanced BPM motor and blower wheel similar to that used in the preliminary study.

Furnace	Blower & Blower motor	Controls
York Diamond 80 P48UA12L06401A 2.5 – 3 Ton AC	Forward curved blades with PSC motor	Speed taps on motor
	Prototype backward inclined with prototype BPM motor	Software on laptop
Carrier 58CTA090-14 88 kBtuh 3.5 ton AC	Forward curved blades (10x8 Blower Size) with PSC motor (1/3 hp)	Speed taps on motor
Carrier 58CVA090-16 2-stage, 88 kBtuh 1.5- 4 Ton AC	Forward curved blades (10x8 Blower) with BPM motor (½ hp)	Circuit board in furnace
	Prototype backward inclined with prototype BPM motor	Software on laptop

The first LBNL laboratory study used the York furnace. The PSC fan is illustrated in Figure 1 and the prototype in Figure 4. The housings of the fans had identical dimensions and mounting flanges. These dimensional and mounting similarities were chosen deliberately because a key application for the prototype air handler is in retrofit applications where it will have to fit in the same space as the fan being removed and connected to the same furnace flanges. The difference between the two housings was an added pair of inlet cones on the prototype for improved aerodynamic entry and an expanded exit to take advantage of the more uniform air flow from rearward inclined blades. This reduced the inlet diameter for the fan from the 9 inches of the standard blower wheels to 7.5 inches. The smaller diameter (4.5 inches rather than 5.5 inches) of the prototype motor prevented the inlet from becoming overly restricted. A significant feature of the prototype blower was the backward facing aerodynamically shaped blades. In addition, the prototype had significantly tighter tolerances than the standard production fan. The inlet cones end much closer to the fan blades; around 1/8 inch (3mm) compared to 1 inch (25mm) in the standard fan we used for comparison. The better tolerances should lead to less energy lost to turbulent recirculation around the blade edges.

A report by GE (Weigman et al. 2003) discusses the development of the prototype air handler in detail. This report disaggregated the efficiency increases for different technical aspects of the prototype air handler: the use of rear (or backward) inclined blades (5 to 10% improvement), using inlet cones to condition the flow (2 to 4% improvement), increasing the outlet area (principally height) of the blower housing (5 to 12% improvement), and cabinet effects (inlet cones reduce efficiency losses compared to outside cabinet testing from 6% to 1%).

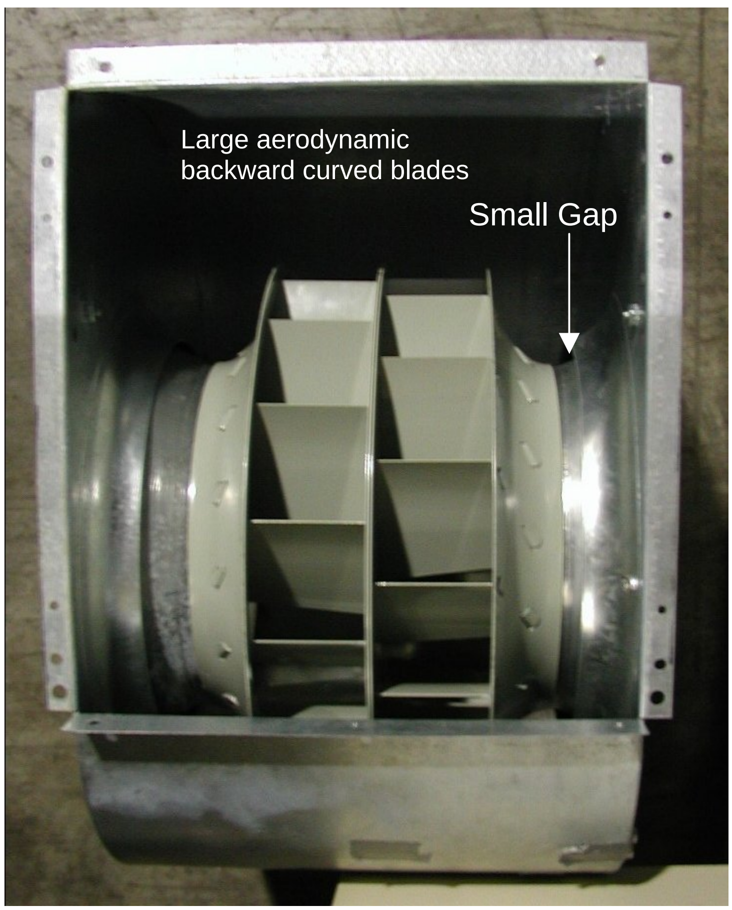

Figure 4. Prototype air handler showing different blade design and fan to housing clearances compared to the standard fan

The fans were tested over a range of air flows and static pressures: 500 to 1000 cfm and 0.4 to 1.2 in. water (100 to 300 Pa). The test results showed that the prototype fan was about twice as efficient as a standard fan (23% compared to 12%). Another prototype was tested by Brookhaven National Laboratory (Andrews et al. 2003) and showed similar results. Using motor efficiency data provided by the manufacturer, the results showed that the motor efficiency was fairly constant about 75%, while aerodynamic efficiency ranged from 12% to 45%, depending on the operating condition. This is to be expected because the aerodynamic efficiency depends on the air velocities over the blades and through the housing, and these velocities change over a wide range depending on total airflow and rotational speed of the fan (670 to 1755 rpm for these tests). The prototype fan was less sensitive to increases in system flow resistance than the standard fan – thus it is more likely to maintain air flows as system flow resistance increases due to damper settings for zone control, or with progressive fouling of coils and filters.

The effect of restrictive cabinets was investigated by reducing the clearance between the fan housing and the air handler cabinet from 2in. (50 mm) to 1 in. (25 mm). The restriction halved the prototype fan efficiency (to 12%) and the standard fan performance was reduced to 9% efficiency. This supports the premise that fans need to be rated in the cabinets that they will be used in. The air flows through the fans were significantly reduced (by up to 22%) by the restriction – it is clear that these restrictions can contribute to the low air flows often found in field installations. If improved motors and fans are to realize their potential they need to be installed in correctly sized cabinets. Cabinet sizes are being restricted due to compact dimensional requirement to enable furnaces to be installed in tight spaces such as basements and attics.

The laboratory tests performed by an outside contractor discussed in Biermayer (2003), examined three fans in the two Carrier furnaces. The contractor attempted to perform AMCA 210 standard tests but found that they could not obtain data for the two BPMs below 0.5 in. water (125 Pa) pressure. Results for this limited data range showed that the BPM fans were only 10 to 20% better than the PSC motor driven fans. The report speculated that the AMCA 210 protocol itself might be the reason for the testing problems.

The AMCA 210 tests in the PG&E air handler test facility have been completed and the testing at LBNL is currently underway. The laboratory test results showed some key characteristics of the different fan/motor combinations:

- BPM motors are better at maintaining airflow as static pressures increase. This means that they are more tolerant to high resistance duct installations in the sense that they are better able to maintain the air flow across heating and cooling heat exchangers so that they operate efficiently. The flip side of maintaining airflow into increasing pressure differences is the corresponding increase in power use. Therefore there is a balance between maintaining heat exchanger effectiveness and the extra fan power requirements.
- Peak overall (motor and aerodynamic) efficiencies are shown in Figure 4 and are about 40% for the prototype air handlers, about 30% for current production standard BPMs and about 25% for PSC motors. For the PSC motors, these peak efficiencies occur at relatively high static pressures: about

0.8 in. water (200 Pa). At more typical operating pressures of 0.5 in. water (125 Pa), the efficiencies drop to 12% to 15%. At typical rating points (about 0.2 in. water (100 Pa)) the efficiencies are even lower at 5% or less. For the current equipment BPM, the efficiency peak is spread out from about 0.5 in water (125 Pa) to greater than 1.0 in. water (250 Pa), with higher efficiencies at lower operating settings. At typical operating pressures there is abroad range from 15 to 30% efficiency depending on the operating setting. This shows that it is important for installers to choose the correct operating settings when installing these air handlers and that different settings may be appropriate depending on the specific installation. The prototype showed similar efficiency value a as the current equipment BPM at normal operating conditions.

- In terms of cfm/W, the PSC air handlers are fairly constant at about 2 cfm/W for all speeds (as shown in Figure 5), with slightly lower cfm/W rating for lower speeds. The performance falls off sharply above about 1.0 inch of water static pressure (250 Pa). In contrast, the BPM devices have significantly higher cfm/W ratings that increase as pressures are reduced, approaching values greater than 15 cfm/W for low pressures.

System Pressures

As these laboratory test data show, the system pressures have a strong influence on BPM motor efficiency, but little impact for PSC motors. Similar to the consensus on measured cfm/W, field studies also have very similar results for static pressures with 0.5 in. water (125 Pa) measured from plenum to plenum. This pressure difference does not include the pressure drops across heat exchangers or coils or air handler cabinet internal pressure changes, but in some cases will include furnace filters. Therefore the static pressure across the fans will be greater, typically 0.8 in. of water (200 Pa). For BPM motors there is the potential to significantly decrease energy consumption if we can reduce this static pressure difference across the fan. The degree to which we can reduce these static pressure differences is mostly limited to reducing the flow resistance of the duct system through good design and installation (e.g., shorter duct runs of larger diameter) because the pressure drops across heat exchangers, coils and filters will always be present. There may be some potential with existing systems to reduce these effects, for example selecting larger coils and using deeper pleated filters. In terms of designing and installing systems to meet a cfm/W performance target, designing and installing a low pressure drop system allows additional flexibility in meeting the target.

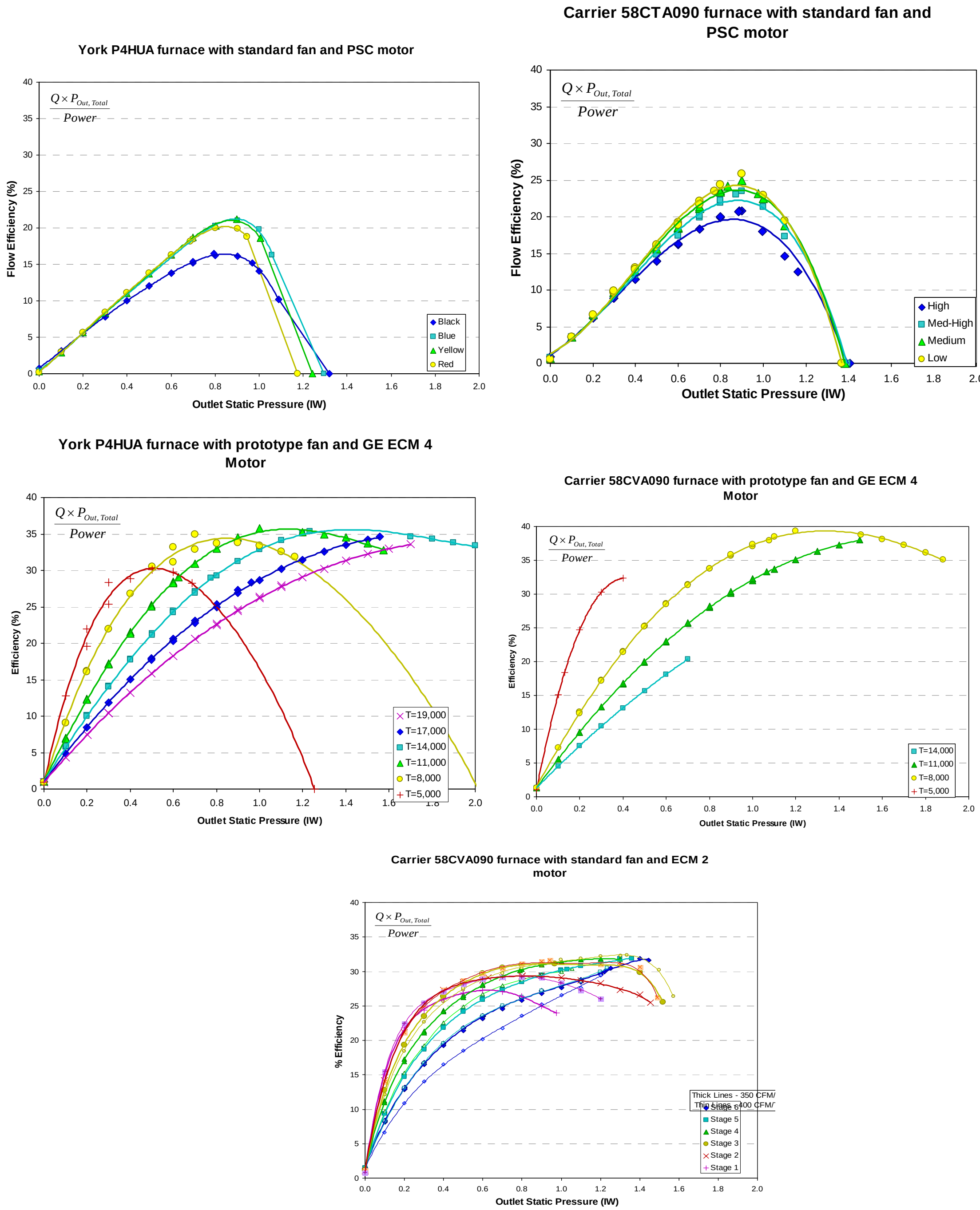

Figure 4. Air handler efficiency from PG&E test facility for five air handlers

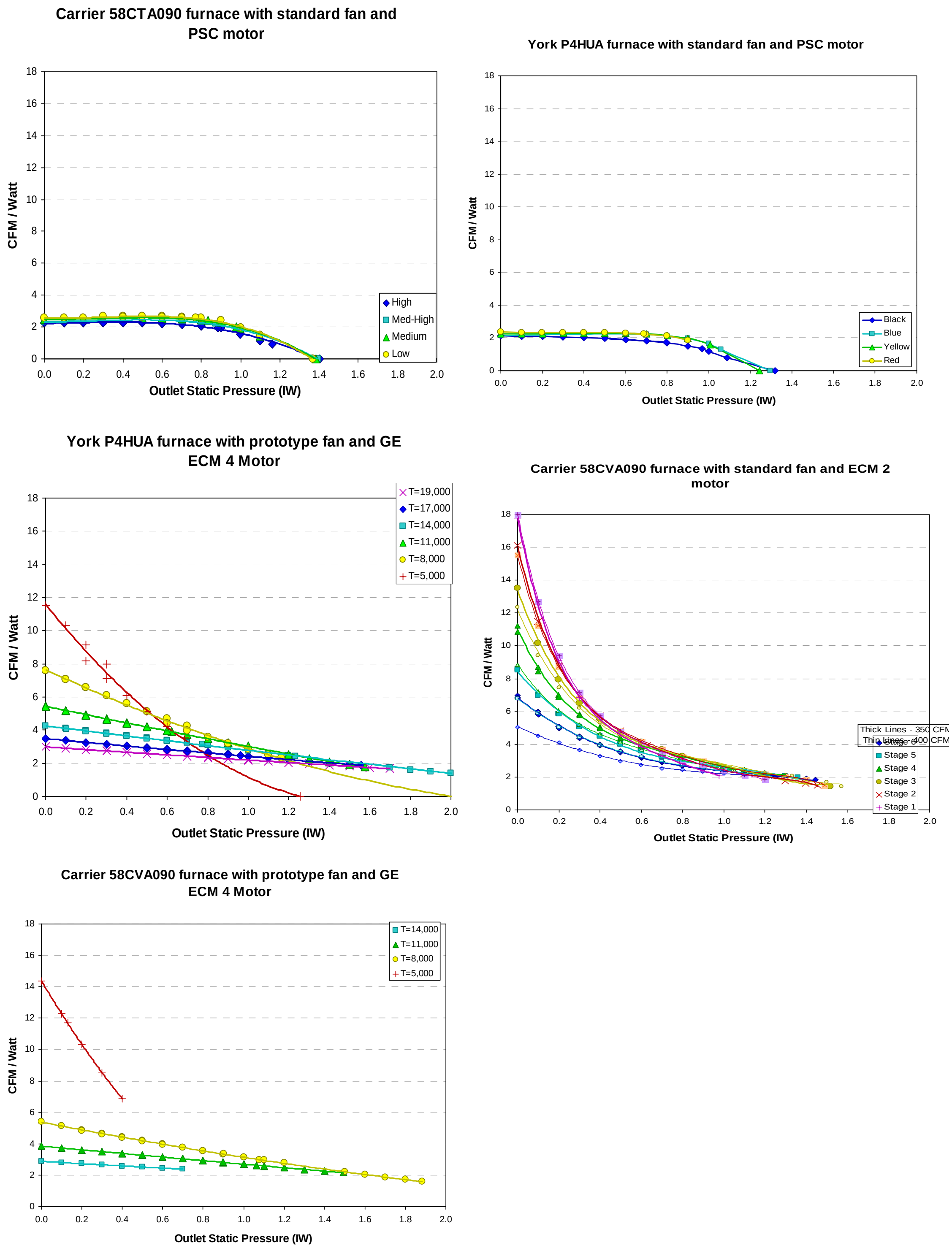

Figure 5. Air Handler cfm/W ratings from PG&E test facility for five air handlers

There is a limit on cfm/W ratings for 100% efficient operation: 8.5 cfm/W/static pressure (in. water) or 2120 cfm/W/static pressure (Pa). E.g., at 0.5 in. water (125 Pa) the theoretical limit is 17 cfm/W. This is illustrated graphically in Figure 6 that shows the large potential benefits for low static pressure systems.

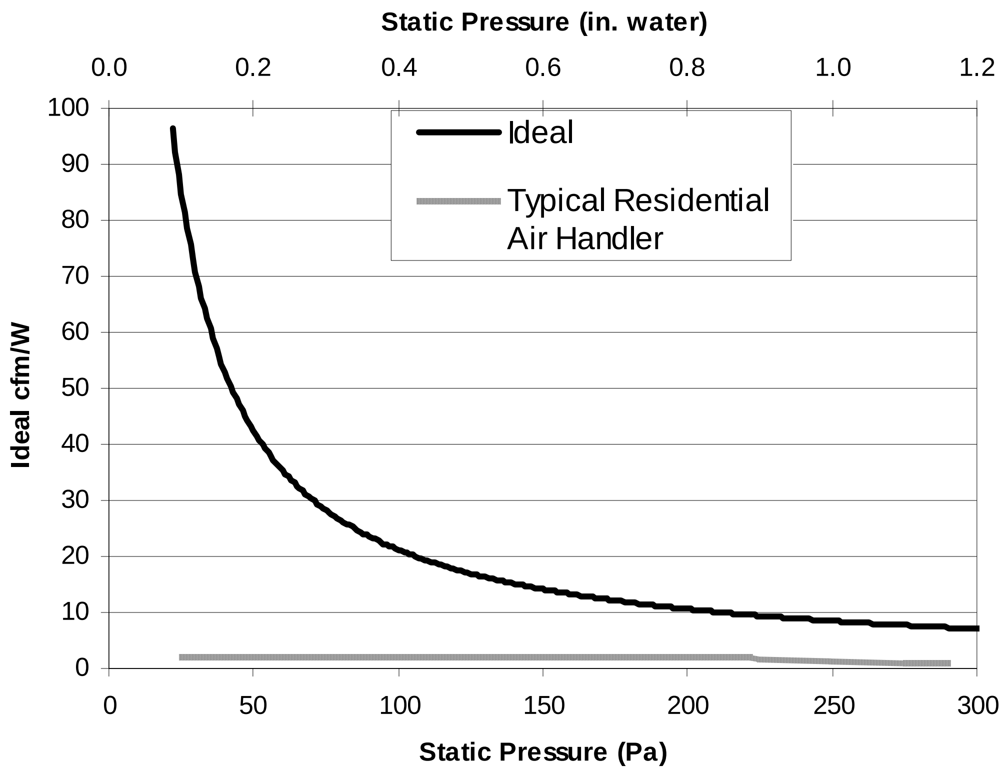

Figure 6. Maximum theoretical cfm/W for different static pressures compared to a typical residential unit

Standards

Part of the reason why there has been little fan efficiency improvement is that air handler fan energy use has not specifically been included in Federal ratings. For example, the SEER and EER rating procedure in ARI Standard 210 (ARI 2003), Section C5.1 allows the use of a default fan power consumption (and capacity reduction) and furnace AFUE ratings only include fossil fuel use. Another issue to consider is the potential of retrofitting more efficient air handlers into existing heating and cooling systems. In addition to providing input to appliance standards, the ability to have standards for the air handler fans separate from those for the heating or cooling equipment they are installed with could yield important energy savings in the retrofit market.

ASHRAE 103 Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers AFUE test procedure

The AFUE test procedure does calculate electricity consumption and it is reported as E_{ae} (Average Annual Electric Consumption) in the GAMA ratings (GAMA (2004)). The GAMA ratings now indicate which condensing furnaces are classified as electrically efficient – i.e., E_{ae} is less than 2% of the total (gas + electric) energy consumption. This is an encouraging effort on the part of the industry to recognize improved air handler performance, although to date only for condensing furnaces. However, the static pressures used in the testing are much lower than those reported in field studies, ranging from 0.18 to 0.33 inches of water (45 to 82.5 Pa) depending on equipment capacity (See Appendix A for more details). The ASHRAE 103 Standard recently went through a review process. Unfortunately, efforts to change the test static pressures to a more realistic 0.5 inch of water (125 Pa) as found in field installations have been unsuccessful.

Because the AFUE quotient does not include the electric consumption of the air handler, there is no current motive for furnace manufacturers to use efficient air handlers. This issue goes beyond the electric motors, fan blades and scroll housings to include the effects of cabinet restriction because cabinets are designed for compact size (to allow for easier installation in restricted spaces). There is no recognition in AFUE for any of these potential improvements.

ARI 210/240-2003 *Standard for Unitary Air Conditioning and Air-source Heat Pump Equipment*

If no fan is supplied with an air conditioner, current SEER and EER ratings allow the use of a default of 365 W/1000 cfm and a capacity reduction of 1250 Btuh/1000 cfm (the same as the 365 W/1000 cfm increase in electrical consumption). This default is considerably less than the 500 W/1000 cfm found in recent field studies. ARI 210 does have the potential to reward more efficient air handlers, however, the potential rating benefit is reduced by the allowed default value because the reference should be higher than this default. Using the default of 365 W/1000 cfm rather than 500 W/1000 cfm reduces the benefit of a 250 W/1000 cfm efficient fan by more than half. When the default is not used, the static pressures used in the testing are much lower than those reported in field studies, ranging from 0.1 to 0.2 inches of water (25 - 50 Pa) depending on the system capacity (See Appendix A for more details). It is not known why the static pressure scales with capacity.

Field study results discussed earlier indicate that the air handler power consumption is about 15% of the total electricity consumed by the air conditioner. As minimum SEER ratings increase, the fraction of power and energy used by the air handler fan will increase proportionally. E.g., for a SEER 17 air conditioner, the air handler use could currently comprise a quarter of the air conditioner energy use (although it is unlikely, given that high SEER equipment tend to use BPMs) and as yet it is unregulated.

Potential Rating Ideas

Laboratory Rating (suitable for adoption in T20 Appliance Standards or a revised ASHRAE 103 Standard)

A key issue is getting enough cooling air flow out of furnaces with high heating fan ratings. We need an appliance rating that rates air handlers for on peak cooling performance. Currently, laboratory ratings heavily reward two-speed systems that run longer at low capacity and air flow rates. This tends to emphasize the low speed operation advantage of BPMs over PSC motors. However, the high speed on-peak operation of BPMs may be no better than PSC motors, and all the advantage is at lower speeds. Therefore a test procedure that is biased toward low speed operation my over estimate energy savings for BPMs. This was shown in field testing by Pigg (2003) and Pigg and Talerico (2004) where the different fraction of low speed operation between the rating procedure and actual field operation leads to the ratings overestimating the fan energy savings for BPMs by over 80%.

A better test method may be to perform the testing at a range of air flows and pressure and have multiple rating points. These should include the highest fan speed (often used for cooling) and the lowest fan speed (for continuous fan-only operation). It is possible that intermediate air flows may not be required if we can show that air handlers do not have unusual operating characteristics such that they can be very efficient at extremes of air flow and pressure but have poor performance at intermediate values. The pressures used in the tests should reflect real world installations and should be at least 0.5 inch of water (125 Pa) at the highest air flow rate. This would set the system air flow resistance that would be kept constant for the lower air flow rating points (as is done in the current ARI 210 standard).

Another issue with laboratory rating is that we do not know if these furnaces will be installed in zoned systems. Zoned systems present their own unique operating issues. The key one is the lack of modulation of capacity or air flow when only one zone is being supplied. This mode of operation can result in extremely high static pressures.

GAMA and CEE have developed a rating criterion that compares annual rated electricity use (E_{ae}) to total input gas and electricity energy for gas furnaces (Mbtuh) from the GAMA ratings. The E_{ae} for an electrically efficient unit should use less than 2% of the total energy (gas plus electricity). New (2004) GAMA ratings now indicate which air handlers meet this criterion (for condensing units only). This approach is also discussed by PG&E (PG&E (2003)) that gives more details of how this criterion was derived from manufacturers' data. There are serious issues with this rating due to several factors (from Wilcox 2005 – personal communication):

- The DOE test procedure on which the proposed criteria is based specifies that the test is done with the air flow rate adjusted to provide a temperature rise 15°F less than the maximum rise set by the manufacturer. For the 40,000 Btu output Air-flow model this results in a test air flow of 606 CFM The furnace is then tested with no filters and an external static pressure which is adjusted to be 0.18 in water for furnaces with inputs less than 55,000 Btu and 0.2 in water for furnaces with input less than 80,000 Btu. So for these single speed furnaces the steady state fan energy input is established with an unrealistically low static pressure and air flow about one half of the cooling air flow. The result is overstatement of the benefits for BPM motors in climates with air conditioning.

- For furnaces on the list with 2 stage burners (Luxaire, Armstrong, American Standard and Rheem, all of the BPM units) the test procedure is modified. A second test is done at the low heating output with a lower cfm calculated at the same rise as the full output test. The external static is significantly reduced to whatever is produced at the lower CFM in the test duct setup used for the high output test. Given the fan laws, the work required to move the air for the low output test will be a fraction of the work required from the fan for the full output test. The annual fan energy is calculated assuming the majority of the heating is done at low speed and the rest at high speed depending on the ratio of heating capacities at each stage. Although this is a reasonable accounting of electricity consumption at the furnace, longer heat residence time in the ducts may offset any electrical or fuel energy savings.

Rather than this approach, it is essential to provide a rating based on tests of the performance parameters that matter to California. This means a rating based on a test where the furnace is running at high speed with a MERV 6 pleated filter, a wet cooling coil and 0.5+ external static pressure delivering 400 CFM/ton of rated cooling capacity.

There may be some barriers to the adoption of different appliance codes in California compared to national (NAECA) standards. For example, AFUE is argued to be the only standard governing furnace energy consumption. However, AFUE does not include electricity consumption in the AFUE rating, so there is a legal/jurisdictional question that needs to be discussed about whether or not California can regulate the electricity use of furnaces. Another issue to be considered here is that most furnaces in California (77% of new construction has central air conditioning (CEC (2004))) are attached to cooling equipment and the electricity use of cooling equipment is regulated separately from furnaces. Lastly, if furnace air handlers are used to distribute ventilation air, then they are being used as part of a ventilation system rather than as a furnace. In these latter two cases, it should be possible to make field measurements of performance under T24 to regulate the electricity consumption of air handlers for these applications.

Field Rating (Suitable for adoption by T24 Energy Efficiency Standards)

Field rating will evaluate actual performance in houses rather than under laboratory conditions that are currently unrealistic. The field rating will account for the higher static pressures found in real furnace installations, the entry effects of how return air enters the air handler (current laboratory procedures leave the bottom of the air handler cabinet open), and will be a much better guide of energy efficiency. An additional benefit of field testing is that it will encourage better duct installations that have lower flow resistance.

A simple approach is to set a minimum performance specification, e.g., 3 cfm/W, and then measure the air flow and power consumption of the air handler under a range of operating conditions. The air handler would be required to meet this minimum specification at all operating points (typically, heat, cool and fan-only). It may be important to have a different specification for continuous fan operation because of the large number of hours in this operating mode during a year. For example, a stricter specification of 5 cfm/W may be appropriate for this operating mode. The field test procedure would use a flow meter (or the current pressure matching technique used in the T24 Alternative Calculation Manual) to measure the air handler flow rate and a power meter to measure the electricity consumption of the air handler. Because optional T24 credits already require the measurement of air handler flow, the only additional measurement requirements are for the air handler power consumption.

Currently, a field study is under way in California to obtain field data on characteristics and efficiency of air handler fans in 60 typical new California homes.

In the 2005 T24 standards (Residential ACM, principally Appendix RE) there are credits given for having the correct air handler flow and for having an efficient air handler. There are two criteria given in the ACM: The first is a default of 300 cfm/ton and 0.01275 W/Btu that corresponds to 1.96 cfm/W. The second is used as a basis for obtaining credit and requires testing to show that there is 400 cfm/ton and uses 0.015 W/Btu cooling that corresponds to 2.2 cfm/W. The procedures in the ACM for measuring air handler power do not explicitly measure the air handler only and will usually include other power draws for controls and possibly the combustion air fan.

Cost issues

Costs are notoriously difficult to estimate given the economies of scale that results from transferring technologies from niche markets to mass markets. Currently there are additional costs associated with using BPMs rather than PSC motors. There is a range of cost estimates from different sources (e.g., Sachs and Smith (2003)) from about $25 (assuming a fully mature market) to over $100. A CMHC (1993) study stated cost premiums of replacing low efficiency motors with high efficiency motors of about C$20 to C$100 (in 1993). GE product literature shows that the retail cost (motor only) of BPMs for residential air handler applications is $90 to $100. Gusdorf et al. (2003) reported Canadian wholesale process of $170 and customer costs of $300. These cost estimates are further complicated by the need to separate the cost to manufacture from the cost to consumers. Lastly, there is the possibility of complete changes in air handler manufacture (e.g., using molded plastic) that could completely change the cost structure. In addition, attention must be paid to retooling issues that may be faced by manufacturers. However, if the physical dimensions, and electric and control requirements are kept the same as current technologies this can be minimized or eliminated. Of course, we also need to really look at the incremental cost over existing PSC motors to find the cost of upgrading to an improved motor. Sachs and Smith (2003) estimated incremental costs of $80 to $90.

From a life-cycle, rather than first cost point of view, the key issue is whether the air handler operates continuously for ventilation or mixing purposes. If continuous operation is used, then the better motors pay off in under a year. On the other hand, if the air handler only operates during heating or cooling operation then the payback times are increased significantly (by about a factor of 5), but are still considerably less than the life of the furnace. The PG&E case study reported positive life cycle costs (a net present value of $245) for non-continuous operation of the air handler. In field studies (Pigg and Talerico (2004)) the potential savings from using BPM rather than PSC motors was offset by different use patterns: systems with BPMs were much more likely to operate in continuous fan operation mode than systems with PSC motors.

New fan designs

The prototype testing discussed above gives an indication of what could be achieved in terms of improved performance using existing technology. A browse though a fan catalog shows that there are many commercially available air handlers suitable for use in residential applications that use improved motors and aerodynamics. In addition, there are some manufacturers (e.g., EBM Papst) that are willing to investigate alternative air handler designs. The use of injection molded plastic rather than sheet metal has a tremendous potential for airflow section blades, better scroll housing design and smoother entry and airflow through the air handler. It is possible that fire safety codes may preclude the use of some plastic in this application and this needs to be looked into in the future.

So what are the barriers to change?

- Little reward for using better fans. Current regulations, codes and standards do not appropriately reward the use of better air handlers, although credit can be taken in SEER ratings and in 2005 T24. As the industry, code and standards bodies and homeowners become more aware of this issue it is likely that rewards will increase.
- As discussed above, currently it may cost more to use more efficient products, but some ideas, such as injection molded plastics, have the potential for significant cost reduction.
- Tooling changes for furnace manufacturers. Again, as shown by the prototype tested above, this issue is easily bypassed by making the external dimensions and mounting flanges compatible with existing furnaces.

Summary

There are clearly substantial energy savings and efficiency gains to be made by improving the electrical (motor) and aerodynamic performance of air handlers. These savings can be realized using existing technologies and have reasonable life cycle costs, with paybacks ranging from less than a year to several years depending on system operation (shorter paybacks occur for continuous operation).

Residential air handler performance has several distinct issues:

- **Electric motor performance.** The current market has two principal motors: PSC and BPM, with BPMs having higher efficiency, particularly at lower air flow rates. A key factor is that BPMs can operate at much lower air flows and therefore are preferable for continuous fan operation for ventilation purposes.
- **Aerodynamic performance.** All residential systems use similar forward curved fans with poor clearance and little attention paid to aerodynamic efficiency. The potential for aerodynamic improvements is greater than that for electric motors. Fans for other applications have much better aerodynamics than those used in air handlers so this issue can be addressed by simply specifying a different blower housing and fan blades. Lastly, attention must be paid to clearance between the fan housing and air handler cabinet walls, as making this gap too small significantly reduces air handler performance.
- **System flow resistance.** Less restrictive ductwork reduces the air handler power consumption and raises the theoretical limit for ratings such as cfm/W. A good fan connected to a poor system can use more electricity than a poor fan connected to a good system. This issue can be addressed in two ways: encouraging and allowing shorter duct runs and better duct layouts, and using field tests to evaluate the combination of air handle and duct system as it is installed. The flow resistance of air filters may play a role in system flow resistance, but only if the filters are very dirty. In addition, the system flow resistance issue also applies to small local ventilation fans whose air flows are often significantly reduced by overly restrictive ducting.
- **Test Procedures and Standards**. Current test procedures do little to reward the use of more efficient air handlers – except as a way to achieve higher SEER ratings. To the industry's credit, GAMA ratings now indicate electrically efficient condensing furnaces. There are legal issues surrounding the ability of other parties (e.g., the Energy Commission) to have air handler efficiency requirements for furnaces because AFUE regulates furnace performance at the federal level. In the future, standards requiring mechanical ventilation should include minimum efficiency specifications for the fans and/or air handler.
- **Current California Standards**. Title 24 currently has credits in the residential ACM for correct air flow and reduced air handler power consumption, although the latter of these may have a problem with giving too much credit.

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Appendix A. External Static Pressures From ASHRAE Standard 103 and ARI Standard 210

From ASHRAE Standard 103:

Table 5
Minimum External Static Pressure
for Electric Central Furnaces

Standard Air Quantity (scfm)	Min. External Static Pressure (in. water)
0 through 849	0.12
850 through 1,599	0.15
1,600 through 2,599	0.20
2,600 through 3,999	0.25

Table 4
Relation of Furnace Input to Minimum Static Pressure*
for Performance and Rating Test Purposes
(all tests performed without a filter)

	External Static Pressure (in. water)		
Input to Furnace (Btu/h)	Oil Furnace with a Temperature Rise Less Than or Equal to 65°F	Oil Furnace with a Temperature Rise Greater Than 65°F	Gas Furnace
55,000 and under	0.38	0.18	0.18
Over 55,000 to 80,000	0.38	0.20	0.20
Over 80,000 to 100,000	0.38	0.23	0.23
Over 100,000 to 200,000	0.48	0.28	0.28
Over 200,000 to 300,000	0.58	0.33	0.33

*These static pressures apply for operation at maximum rated input only.

From ARI Standard 210:

Table 6. Minimum External Pressure

Standard Capacity Ratings [1]		Minimum External Resistance	
MBtu/h	kW	in H_2O	Pa
≤ 28	≤ 8.2	0.10	25
> 28 and ≤ 42	> 8.2 and ≤ 12.4	0.15	37
> 42 and < 65	> 12.4 and ≤ 19.0	0.20	50

[1] Cooling capacity for units with cooling function; High Temperature Heating Capacity for heating-only units